XI. *On the Conductivity of Gases under the Becquerel Rays.*

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§ 1. *Introduction.*

It has been known almost from the first discovery of the Becquerel Rays that these mysterious emanations caused gases through which they passed to conduct electricity. But though careful measurements have been made of the relative conductivity* of gases under the Röntgen rays (J. J. Thomson, 'Proc. Camb. Phil. Soc.,' vol. 10, p. 9) and under cathode rays (MacLennan, 'Proc. Roy. Soc.,' vol. 66, p. 375), little seems to have been done in this direction for the Becquerel rays. This paper deals with measurements of the kind in question, and with the conclusions which may be drawn from them. It will be first desirable to state clearly what conditions must be complied with in order that the quantities measured may have an intelligible meaning.

In the first place, the E.M.F. applied to the conducting gas must suffice to "saturate" the current. In other words, it must be so great that a further increase will not increase the current appreciably (see J. J. Thomson, 'Phil. Mag.,' November, 1896). In the second place, it is essential to make certain that the layer of gas employed is so far rarefied that the absorption of the radiation by it is inappreciable. If this condition is not complied with, the layers of gas more remote from source of radiation are less powerfully affected by it than the nearer ones. The effective strength of the radiation will thus depend on the absorbing power of the gas at the particular pressure, and the observed ratio of conductivities of two gases at the same pressure will not represent the ratio of their conductivities under radiation of a given strength.

It is universally recognised that the conductivity of gases under Röntgen and Becquerel rays is due to the production in them of positive and negatively charged

* It is hardly necessary to state that the word "conductivity" applied to an ionised gas is used in quite a different sense from the same word when applied to a metal. The expression "conductivity" of a gaseous conductor is used to denote the current which it will carry under a saturating electromotive force.

ions by the rays. When the current is saturated, the ions travel across from one electrode to the other so quickly that there is no time for recombination to take place to any appreciable extent. Thus the current measures the amount of ionisation produced, supposing the strength of radiation to remain constant. In order to determine whether or not the radiation was sensibly absorbed, the conductivity was observed at different pressures. When the conductivity was proportional to the pressure, it was concluded that no sensible absorption took place in the layer of gas at any pressure within the range of the experiment. When, on the other hand, the conductivity did not increase so fast as the law of proportionality to the pressure would require, it was clear that the absorption was appreciable. In such a case, the gas was rarefied far enough to ensure that the law of proportionality should be obeyed.

§ 2. *Radio-active Substances.*

The radiation from various radio-active bodies has been investigated. These included—

(1.) A preparation obtained from DE HAEN, of Hamburg (see 'Wied. Ann.,' vol. 68, p. 902). This substance, as a few simple chemical tests showed, consists principally of barium carbonate, and, no doubt, its very strong radiating power is due to the presence of the new metal, radium, discovered by Madame CURIE in pitchblende, which is separated, together with barium, in the analysis of that mineral.

This radium preparation gave out radiations of at least two distinct kinds: one easily absorbable by solids or gases, and, as CURIE has shown ('Comptes Rendus,' vol. 130, p. 73), not deflected by magnetic force. The other, more penetrating, and deflectable by the magnet. The relative conductivities in gases due to each of these kinds has been investigated.

Since, when investigating the conductivity due to the non-deflectable kind, the other variety were also present, it is important to inquire whether the proportion is large enough to vitiate the results.

In CURIE's paper the following numbers are given, showing what proportion of the conductivity is due to the non-deflectable rays at various distances from the source:—

Distance centim. . . .	7·1	6·9	6·5	6·0	5·1	3·4
Percentage	0	0	11	33	56	74

The absorption of the air, of course, accounts for the small proportion at long distances. A rough extra-polation from these numbers shows that close up to the

substance only about 10 per cent. of the ionisation is due to deflectable rays. The conductivity ratio to be measured did not differ in any case more than about 30 per cent. for the two kinds of rays. Thus the error due to the presence of deflectable rays is only of the order of 3 per cent., an amount not well outside the errors of experiment.

(2.) A preparation containing the other radio-active constituent of pitchblende, polonium. This body I obtained as follows :—

Pitchblende was dissolved in dilute nitric acid. The filtered liquid was treated with sulphuretted hydrogen. The precipitate was found to contain antimony, arsenic, copper, and bismuth, the polonium being associated with the last. To remove antimony and arsenic, the precipitate was digested with ammonium sulphide. The liquid was filtered off, and the remaining precipitate, containing copper and bismuth, with polonium, was dissolved in nitric acid, and excess of ammonia added. The resulting precipitate, consisting of bismuth and polonium hydroxide, was tested for radio-activity, and found to be fairly active. Some of it was fused with an excess of potassium cyanide with a view to reducing it to the metallic state. The contents of the crucible, digested with water, and filtered, gave a black insoluble powder, not a coherent button of metal as had been anticipated. This black powder presumably consisted of the reduced metal. It was many times more active than the original oxidised product, and was accordingly used in the experiments.*

(3.) Another specimen of polonium was used which I owe to the kindness of Sir WILLIAM CROOKES. I have no exact account of the method of preparation, but Sir W. CROOKES tells me that it was, in outline, the same as that described by CURIE ('Comptes Rendus,' vol. 127, p. 175). This substance was considerably more powerful than the polonium which I prepared.

(4) Ordinary uranium compounds, as met with in commerce, have a feeble radio-activity. Indeed, it was in these that BECQUEREL first detected the effect. Sir W. CROOKES has shown ('Proc. Roy. Soc.,' vol. 66, p. 409) that the activity is due, not to the uranium itself, but to a powerfully radiating body accompanying it in small quantities, and probably distinct from both radium and polonium. He has shown (*loc. cit.*) that if ordinary commercial crystallised uranium nitrate be dissolved in ether, the resulting liquid divides into two layers—the one consisting mainly of an aqueous, the other of an ethereal, solution of uranium nitrate. The water, of course, is supplied by the water of crystallisation of the salt. The solid obtained by evaporating the aqueous solution is distinctly more powerfully radio-active than that from the ethereal one. In my experiments a product was used which had been several times concentrated in this way.

* The improvement in the polonium due to treatment with potassium cyanide at a red heat was so marked, that it does not seem possible to explain it by the greater concentration of the material when in the metallic condition. The observation is of some interest, and I hope to investigate the matter further; but it bears only indirectly on the subject of the present paper.

Uranium, as well as radium, gives off two types of radiation, one much more penetrating than the other. (See RUTHERFORD, 'Phil. Mag.,' January, 1899.) BECQUEREL has shown ('Comptes Rendus,' vol. 130, p. 1583) that some at least of the uranium rays are deflected by the magnet, but he does not seem to have made any experiments to decide whether both types are so, or only one. In fact, the radiation is so feeble as to make such experiments very difficult. But it seems probable that, as in the case of radium, the penetrating type of rays are deflected, while the others are not so.

My experiments were exclusively concerned with the rays from the bare compound, which consist for the most part of the easily absorbed type. Only a small fraction of the total conductivity is due to the other kind, so small, in fact, as to make any determination of the conductivities difficult, unless some more powerful preparation than mine were available. The experiments were accordingly confined to the easily absorbed type of radiation.

§ 3. *Method of Experimenting.*

The gas of which the conductivity was to be determined occupied the space between two parallel plate electrodes. One of these was maintained at a high potential, the other connected to the one pair of quadrants of an electrometer, the other pair being to earth. The rate of movement of the needle then gave a measure of the current through the gas.

When the rays which had penetrated through a considerable thickness of metal were to be investigated, the arrangement was as follows:—

The gas of which the conductivity was to be determined was contained in the apparatus represented in section by fig. 1. It consists of an air-tight cylindrical brass box *a*, about 1 inch long, 3 inches diameter, provided with a bottom of thin copper sheet *b*, soldered on, through which the rays penetrated into it. The bottom was ·007 centim. thick. Inside this cylinder, and parallel to its ends, was the insulated metal plate *f*, carried on the rod *g*. This plate was used as the low-potential electrode.

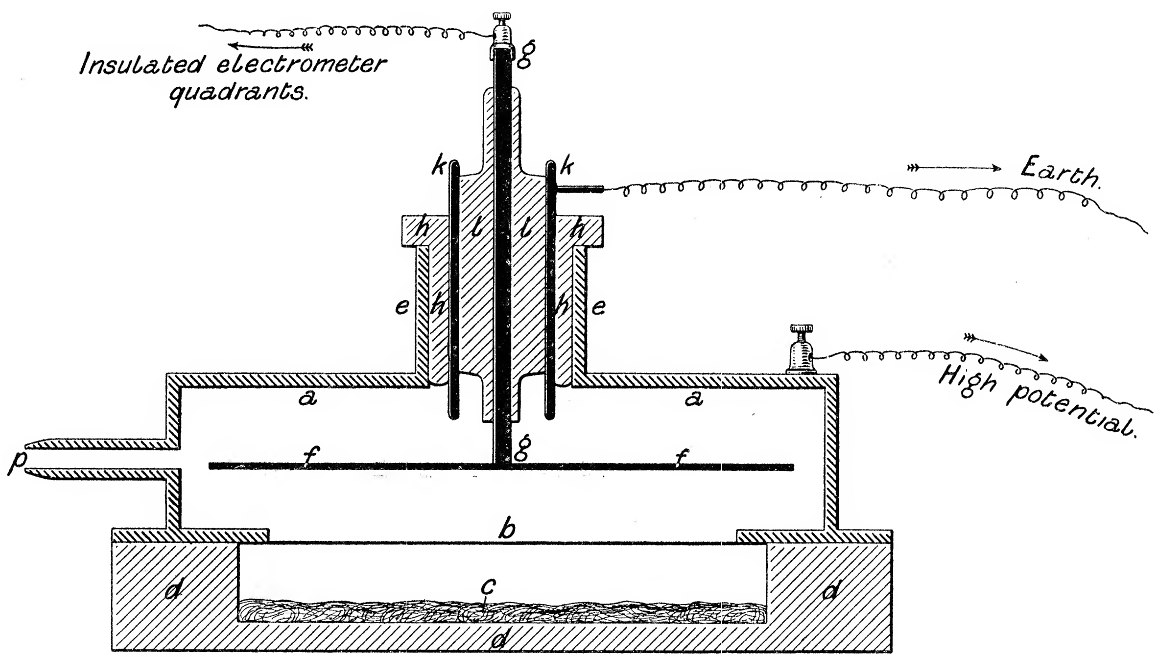
The arrangements for insulating the plate *f* from the outside cylindrical brass box, which served as the high potential electrode, were somewhat special.

At *e e* is seen the brass neck of the main vessel. Inside it is fixed an ebonite collar *h*, and inside this again a second brass tube *k*. This inside brass tube carries the ebonite stopper *l*, up the middle of which the brass wire *g* passes. This latter carries the electrode *f*, and is connected outside to the electrometer. The intermediate brass tube *k* is put to earth. Finally, the outside vessel is put to the + terminal of a battery of 100 storage cells, the other terminal of which is to earth.

The ebonite collar *h* has thus to sustain an E.M.F. of 200 volts; but the ebonite stopper *l* has only to sustain 3 or 4 volts, since the potential to which *f* was allowed

to rise, in order that a suitable reading of the rate of charge might be obtained, never exceeded this value. Now a slight leakage through h is of no importance, its only effect being to take a small current from the battery. On the other hand, a failure of the insulation of the stopper l would vitiate the measurements. But the danger of such a failure is but small, because of the smallness of the E.M.F. to which this insulation is exposed. If a simple ebonite stopper were used to carry the electrode, these more complicated arrangements being dispensed with, it would be essential that its insulation should be perfect even when exposed to the whole 200 volts.

Fig. 1.



The brass vessel was screwed down to a block of lead, d, by suitable thumbscrews. A circular cavity, c, was turned in this block, and served to contain the radio-active material.

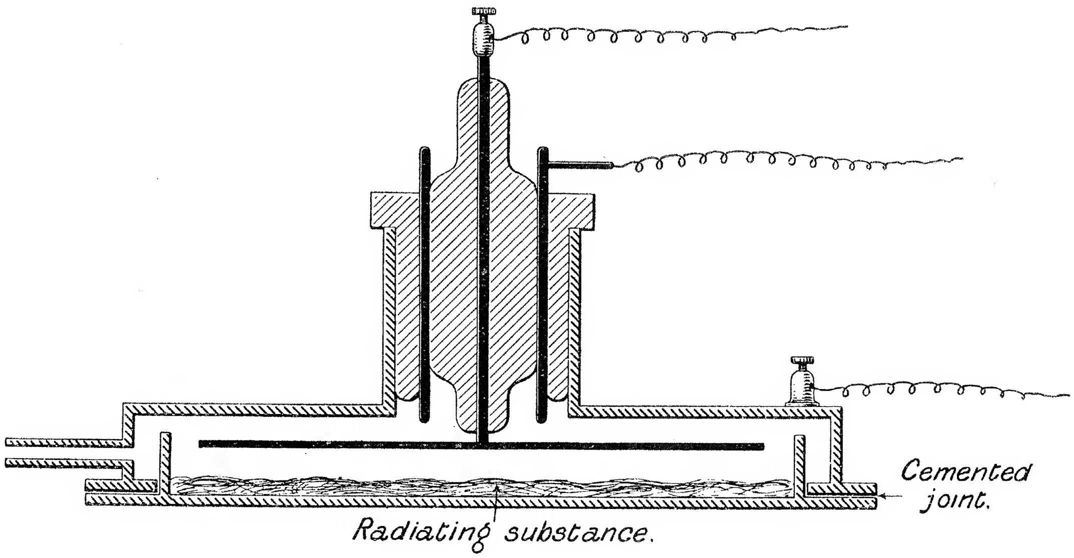
At p a side tube was soldered in, through which the apparatus could be exhausted and gas admitted.

For investigating the easily absorbable radiation, a slightly different arrangement was employed. Instead of the thin copper bottom soldered on, a thick circular brass plate was used. On this was laid a lead tray containing the radio-active body; the brass cover, in this case provided with a flange round the bottom edge, was then cemented on with the soft cement known as PROUT'S Elastic Glue.

Fig. 2 will make the arrangement clear. The vessel inside was connected to a water-pump, which would exhaust to a pressure of 15 millims., and to a manometer.

The procedure in investigating each kind of radiation was as follows:—First, the rate of leak was taken in air at different pressures; the limit of pressure within which the rate of leak was sensibly proportional to the pressure was thus ascertained. And in the subsequent measurements care was taken to be well inside this limit.

Fig. 2.



In comparing the different gases, air was in all cases taken as the standard. The rate of leak in air was measured at a pressure such as to give this rate a convenient value. The air was then removed by the water-pump, and the gas under investigation admitted. The apparatus was several times exhausted and refilled to ensure purity. Finally, the pressure was adjusted to give about the same rate of leak as that previously measured in air, and the exact rate carefully determined. If $p\ p'$ were the pressures of the gas under investigation and of the air respectively, $i\ i'$ the observed rates of leak, then the relative saturation conductivity of the gas was given by the fraction $\frac{i\,p'}{i\,p}$, air at the same pressure and under radiation of the same strength being taken as unity.

The electromotive force used was 200 volts, amply sufficient to produce saturation under the conditions of the experiments.

In investigating the vapours of volatile liquids, such as methyl iodide, it was necessary to take care that the vapour should not be so nearly saturated as to deviate sensibly from BOYLE'S law. The rates of leak through vapours were accordingly taken at a pressure of not more than half that which would have been in equilibrium over the liquid at the same temperature. These vapours gave large conductivities, and the smallness of the pressure at which it was necessary to work did not cause any inconvenience.

I shall now mention the methods of preparation of the gases employed. It would not have been worth while, in view of the limited accuracy of the electrometer measurements, to have taken more than ordinary care to secure purity.

The gases were in all cases dried by passing them slowly over phosphorus pentoxide.

The *hydrogen* was prepared from sulphuric acid and zinc, and purified by occlusion in palladium foil, from which it was subsequently expelled by heat.

The *oxygen* was obtained by heating potassium permanganate.

The *hydrochloric acid* was made by the action of pure sulphuric acid on rock salt.

The *cyanogen* was obtained by heating mercury cyanide.

The *carbon dioxide* by the action of pure hydrochloric acid on white marble.

The *sulphur dioxide* from the liquefied gas commercially supplied, in a "syphon."

The *chloroform*, *methyl iodide*, and *carbon tetrachloride* vapours were from the pure liquids commercially procured.

§ 4. *Experiments on the Penetrating Radiation from the Active Barium Compound.*

The vessel used to contain the gas was that with the thin copper bottom, ·007 centim. thick, through which the radiation had to pass. As any easily absorbable radiation had already been filtered out by the copper bottom of the vessel, it was not to be expected that the rate of leak would be otherwise than simply proportional to the pressure; but it was thought best to test this experimentally, partly as a guarantee of the accuracy of the method of measurement.

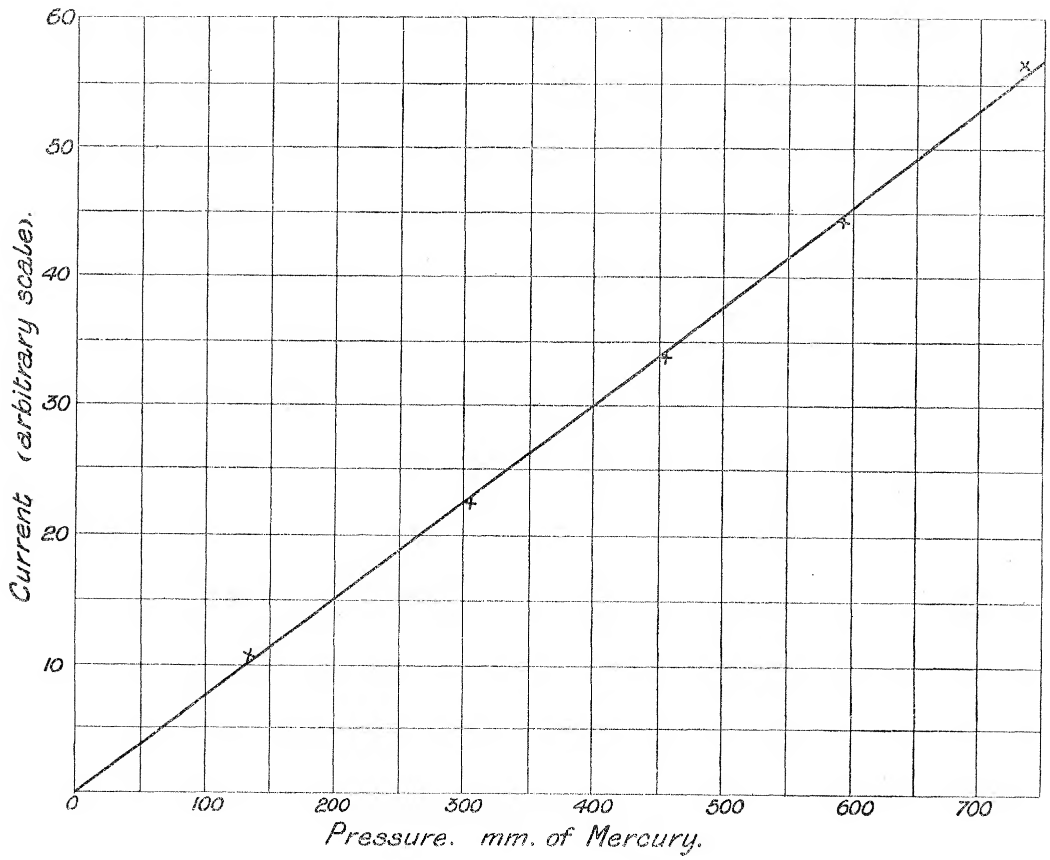
The following measurements were obtained :—

Pressure of air, millims. of mercury.	Time taken for electrometer needle to pass over 50 scale divisions.	Current (arbitrary scale).
	seconds.	
735	17·7	565
591	22·6	443
454	29·4	340
306	44·6	224
136	95·6	105

The measurements of the rate of leak were in each case the mean of about six observations. The results are plotted on diagram No. 1, and it will be seen that the rate of leak is closely proportional to the pressure up to atmospheric pressure, as was anticipated. It was safe, then, to employ any pressure within that range.

The first experiments were made on hydrogen. These will be given in full as specimens. In the other cases only the results of each determination will be given.

Diagram No. 1.—Radium. Penetrating Radiation.



Hydrogen.—Three entirely separate determinations were made, with different samples of gas.

(1.) Air. Pressure 144 millims.

30 scale divisions of electrometer passed over in—

55·5 57 55 57 57 59 55·5 seconds.

Mean 56·4 seconds.

Hydrogen pressure 727 millims.

30 scale divisions in—

73·5 71·5 73·0 73·5 71·0.

Mean 72·5 seconds.

Conductivity of hydrogen $= \dfrac{56{\cdot}4 \times 144}{727 \times 72{\cdot}5} = {\cdot}154$ (air = 1).

(2.) Air. Pressure 123 millims.

30 scale divisions in—

66·5 64·5 63·5 65 66 seconds.

Mean 65·1 seconds.

Hydrogen pressure 696·5 millims.

30 scale divisions in—

72·5 74·5 73·0 75·0.

Mean 73·75 seconds.

Conductivity of hydrogen $\frac{65 \cdot 1 \times 123}{696 \cdot 5 \times 73 \cdot 75} = \cdot 156$ (air = 1).

(3.) Hydrogen. Pressure 347 millims.

30 scale divisions in—

137 133 134 132·5.

Mean 134·1 seconds.

Air pressure 129·3 millims.

30 scale divisions in—

57·5 57 58·5 58.

Mean 57·75 seconds.

Conductivity of hydrogen $= \frac{57 \cdot 8 \times 129 \cdot 3}{134 \cdot 1 \times 347} = \cdot 161$ (air = 1).

We have then as the results of these three determinations—

Conductivity of hydrogen ·154, ·156, ·161.

The final mean value being ·157.

The results for the other gases will now be given in a tabular form, since no good purpose would be served by writing them out at full length. To make the table complete, the results for hydrogen will be repeated.

Nature of gas.	Relative conductivity (air = 1).			
	Separate determinations.			Mean.
Hydrogen	·161	·154	·156	·157
Oxygen	1·22	1·23	1·28	1·21
Hydrochloric acid	1·48	1·52	1·38	1·46
Carbonic acid	1·61	1·57	1·54	1·57
Cyanogen	1·82	1·81	1·84	1·82
Sulphurous acid	2·35	2·33	2·27	2·32
Chloroform	4·83	4·98	4·87	4·89
Methyl iodide	5·22	5·33	4·98	5·18
Carbon tetrachloride	5·93	5·78	—	5·85

The observations on hydrochloric acid gas are not to be relied on. This gas rapidly attacked the metal of which the apparatus was made. The chlorine no doubt combined with the metal, setting the hydrogen free. The pressure rapidly diminished if the apparatus was left standing full of the gas. No doubt the difficulty might have been avoided by using an apparatus of platinum, but it was thought hardly worth while to go to the trouble and expense which this would have involved. It is to be regarded as a matter of accident that the separate determinations agree with one another as well as they do. In the other cases I believe the mean results are not, for the most part, more than 2 per cent. from the truth, if so much.

The discussion of these results, as well as those that follow, will be deferred till the end of the paper.

It will be worth while to mention that the conductivities of hydrogen and air were compared when an additional sheet of copper, equal in thickness to that which formed the bottom of the vessel (·007 centim.), was used to cut down the radiation. Almost exactly the same ratio as before was found. So far as this property is concerned, the radiation which penetrates one sheet of copper ·007 centim. in thickness is homogeneous.

§ 5. *Easily Absorbable Rays from Radio-active Barium Carbonate.*

To investigate the easily absorbable rays, the second form of apparatus was used, the radiating body being in contact with the gas under investigation, without the interposition of any solid partition. The radiation from the barium compound is enormously reduced by the interposition of so thin a screen as an ordinary piece of tinfoil; these "soft" rays accordingly form much the greater part of the whole. They cannot be conveniently separated from the penetrating rays used in the above experiments, but these latter are present in so small a proportion that they do not much affect the results (see above, p. 508). As is there mentioned, there is a difference in kind as well as in degree between the behaviour of the two types of rays. The penetrating rays are deflected by the magnet; the others are not so.

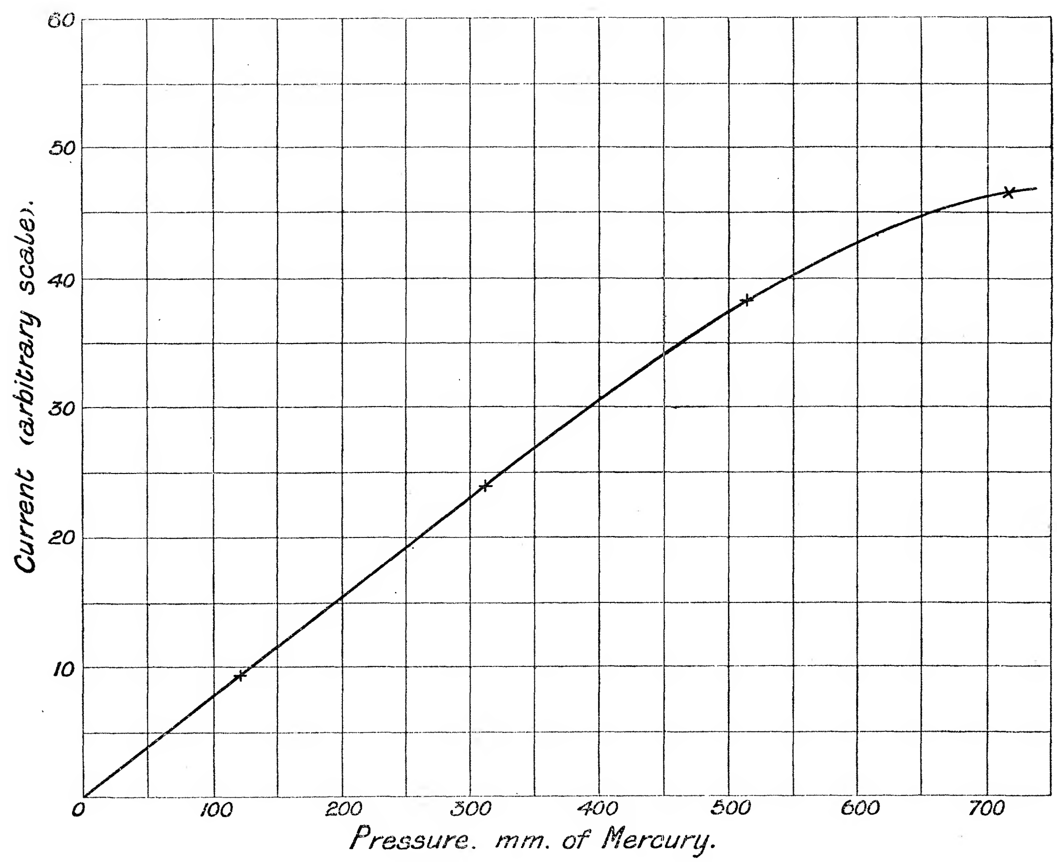
The barium compound was so very active that even when a very small quantity was taken, and the air pressure considerably reduced, the rate of leak was much too large for convenient observation. A parallel plate condenser was accordingly connected to the electrometer so as to increase its capacity. The distance between the plates was adjusted till the rate of leak had a convenient value, and was not afterwards altered. This plan is much better in practice than diminishing the sensitiveness of the electrometer by lowering the potential of the needle.

The rate of leak in air was determined at various pressures.

Pressure, millims.	Time taken to pass over 100 scale divisions (mean of 5 observations).	Current (arbitrary scale).
719	21·4	467
517	26·1	383
313	41·6	240
121	101·0	83

The results are plotted on diagram No. 2. Here the absorption of the radiation by the air is quite perceptible. The current is sensibly proportional to the pressure for pressures less than half that of the atmosphere. In comparing different gases, this limit of pressure was not exceeded.

Diagram No. 2.—Radium. Easily absorbed Radiation.



The measurements are given in the following table :—

Gas.	Conductivity (air = 1).				
	Separate determinations.				Mean.
Hydrogen	·218	·224	—	·212	·218
Sulphur dioxide . .	1·89	2·00	1·92	2·10	1·98
Methyl iodide . . .	3·78	3·72	3·82	36·3	3·74

§ 6. *Radiation from Polonium.*

This radiation is not deflected by the magnet* (CURIE, 'Comptes Rendus,' vol. 130, p. 73), and, so far at least, resembles the "soft" radiation from the active barium. The first set of experiments was made with the sample of polonium prepared by myself. The following numbers give the rate of leak at various pressures; about five observations were made in each case, and the mean taken.

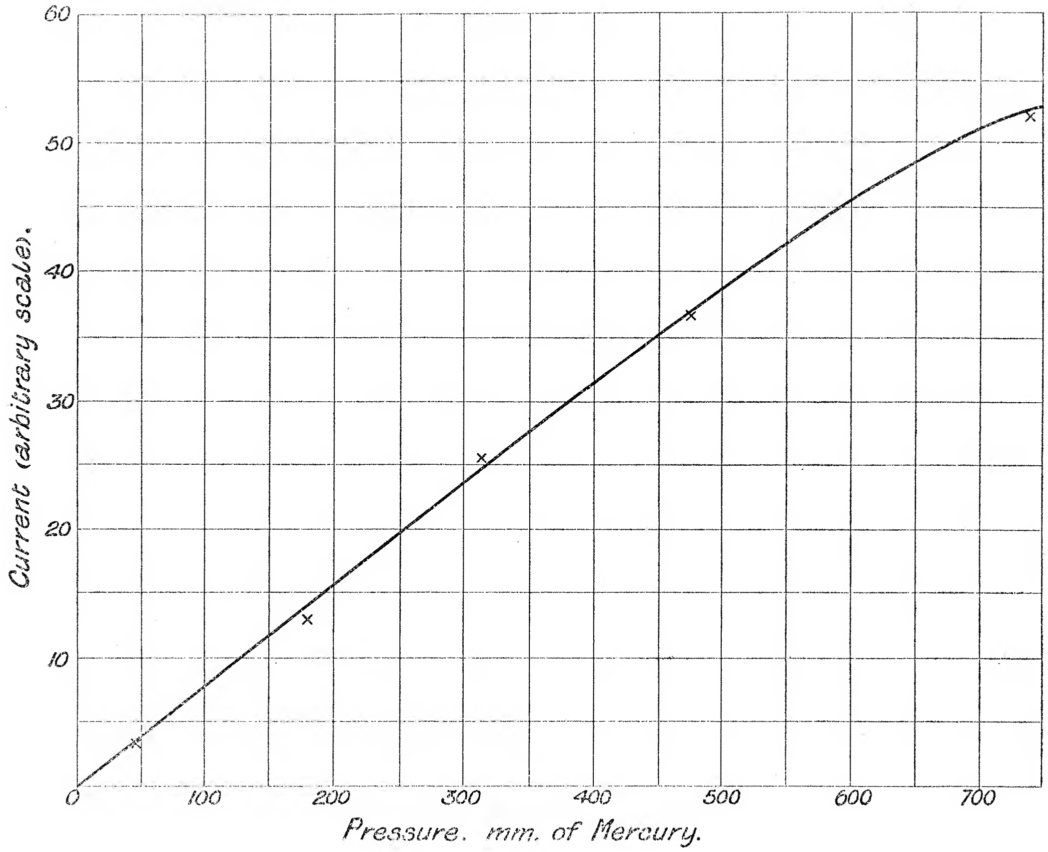
Pressure, millims.	Time taken to pass over 100 divisions.	Current (arbitrary scale).
740	19·2	521
477	27·3	366
315	39·3	255
180	76·9	130
46	302·0	33

The results are plotted on diagram No. 3. There is not much indication of absorption until the pressure is comparable with that of the atmosphere. For the various gases, the following results were obtained :—

Gas.	Relative conductivity (air = 1).				
	Separate determinations.				Mean.
Hydrogen	·215	·226	·242	·215	·226
Oxygen	1·13	1·16	—	1·18	1·16
Carbon dioxide . .	1·53	1·55	—	1·54	1·54
Cyanogen	1·95	1·93	—	—	1·94
Chloroform	4·42	4·45	—	—	4·44
Sulphur dioxide . .	1·96	2·02	2·14	—	2·04
Methyl iodide . . .	3·32	3·88	3·43	3·42	3·51
Carbon tetrachloride.	5·30	5·37	—	—	5·34

* This result is not in agreement with that arrived at by GIESEL ('Wied. Ann.,' vol. 69, p. 834). But my own experience confirms CURIE'S conclusion.

Diagram No. 3.—Polonium, prepared by Author.



These experiments, as I have said, were made with polonium of my own preparation. Some of the experiments were repeated, using the more powerful polonium preparation of Sir W. CROOKES.

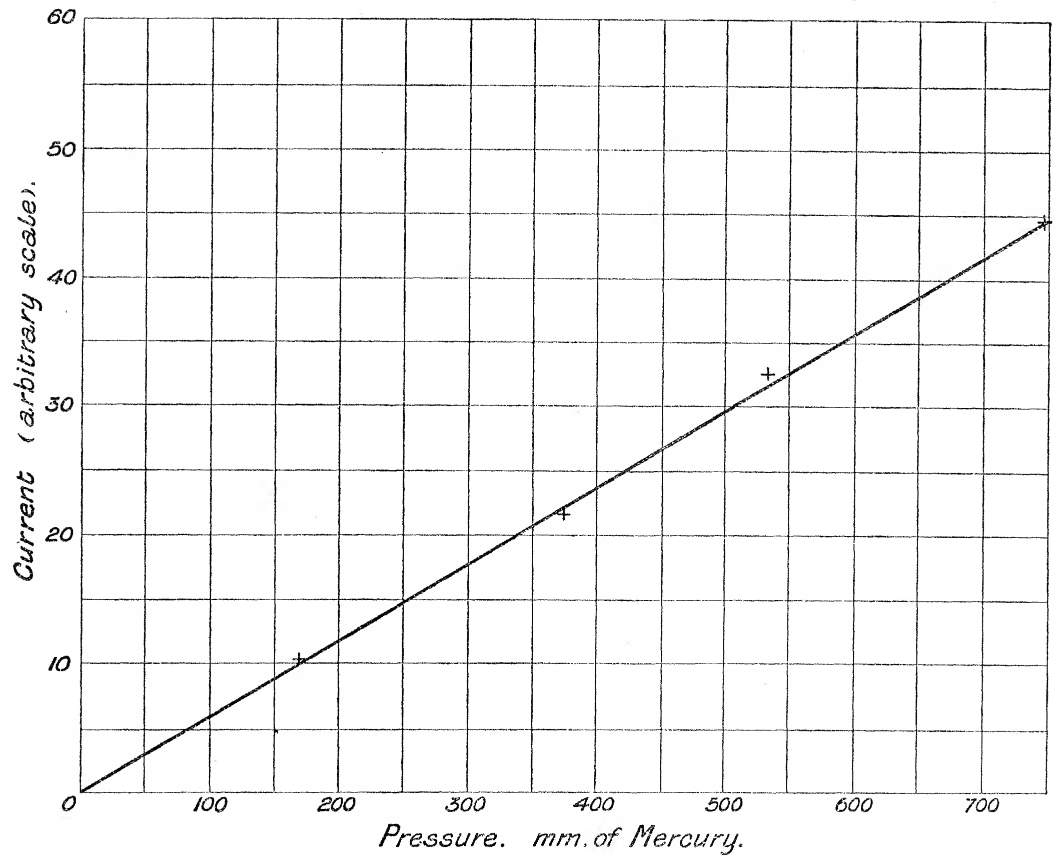
The rates of leak at different pressures were determined, with the following result :—

Pressure, millims.	Time taken to pass over 100 electrometer divisions.	Current (arbitrary scale).
	seconds.	
749	22·4	446
535	31·7	316
375	45·8	218
170	98·4	102

See diagram No. 4.

The rate of leak is here sensibly proportional to the pressure throughout the entire

Diagram No. 4.—Polonium, prepared by Sir W. CROOKES.



range. The radiation from this polonium preparation appears to be more penetrating than that from the other.

The next table gives the relative conductivities found with this radiation.

Gas.	Relative conductivity (air = 1).				
	Separate determinations.				Mean.
Hydrogen	·232	·222	·213	·210 ·216	·219
Sulphur dioxide . .	1·99	2·15	—	2·12	2·03
Methyl iodide . . .	3·44	5·48	—	3·51	3·47

The mean values do not differ much from those found for the other sample of polonium. There is not, I think, any evidence that the relative conductivities are not exactly equal in the two cases.

§ 7. *Radiation from Uranium Salt.*

The uranium salt having been placed in the apparatus, the rates of leak were observed at various pressures, with the following results :—

Pressure, millims.	Time taken for electrometer needle to pass over 100 divisions.	Current (arbitrary scale).
	seconds.	
726	27·7	361
565	32·6	307
372	44·5	225
176	81·4	123
116	116	86

Diagram No. 5.—Uranium.

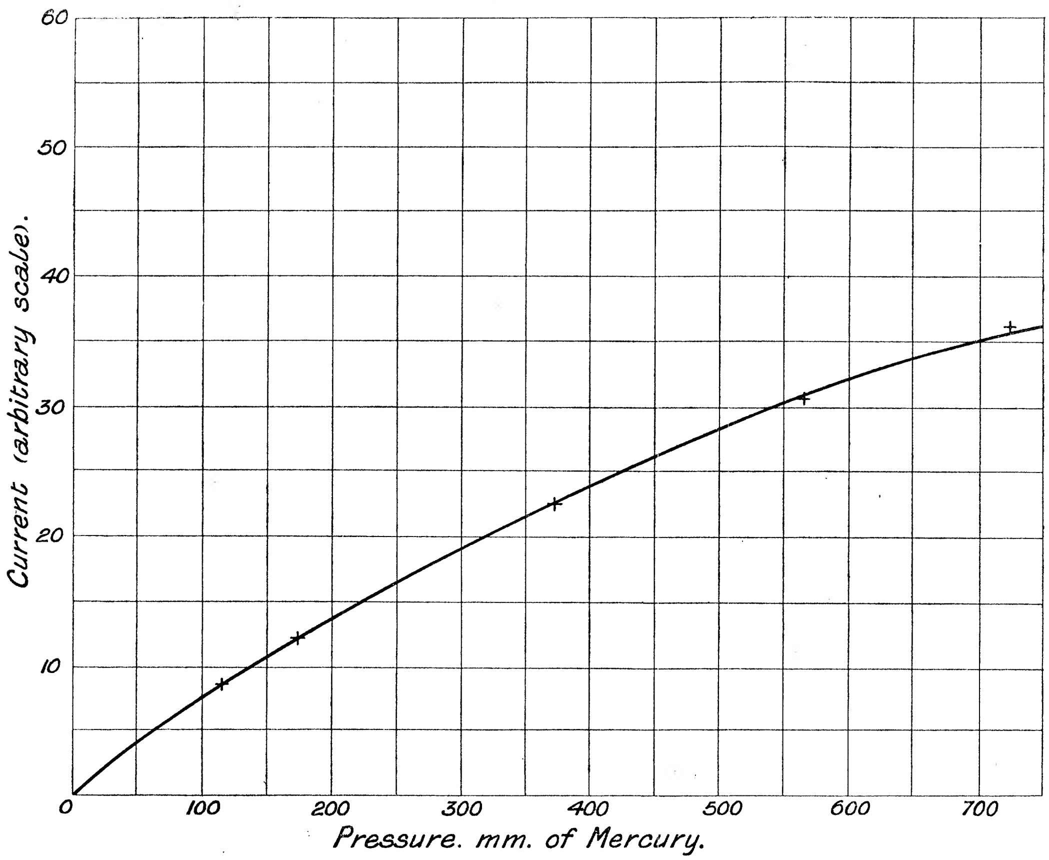


Diagram No. 5, which exhibits these results graphically, shows that for this type of radiation the current begins to deviate appreciably from that value which proportionality to the pressure would require, when the pressure only amounts to

about 150 millims. This type of radiation is, therefore, more rapidly absorbed by the air than any of the kinds which have already been discussed. The rate of leak at pressures so low was rather too small for convenient measurement. A somewhat different method of comparing the gases was used, which avoided this difficulty. The rate of leak was taken in air, at some convenient pressure, usually about 250 millms., and afterwards at a slightly greater pressure, perhaps 260 millims. The gas for comparison having been introduced into the vessel, its pressure was adjusted till the rate of leak was intermediate between those given by air at the two slightly different pressures. The pressure at which the air would have given the exact rate of leak observed in the other gas was determined by interpolation, on the sufficiently accurate assumption that the rate of leak could be represented between these narrow limits as a linear function of the pressure.

In this way, then, were determined the pressures at which the two gases gave exactly the same rate of leak.

If now we assume that the absorption of the radiation by a gas is proportional to the saturation conductivity produced in the gas, it follows that if two gases are adjusted to give equal conductivity, the radiation is absorbed to an equal extent in each. Consequently the correction for absorption of the radiation is eliminated, and the relative conductivities are inversely proportional to the observed pressures.

The assumption that the absorption by a gas is proportional to the conductivity produced in it, is justified by RUTHERFORD's experiments ('Phil. Mag.,' Jan., 1899, p. 137). He found that if practically the whole of the radiation was absorbed, all the gases tried gave nearly the same rate of leak under a saturating electromotive force. This implies the truth of the relation in question. The next table gives the values found for uranium radiation, with the different gases.

Gas.	Relative conductivity (air = 1).				
	Separate determinations.				Mean.
Hydrogen	·208	·209	·214	·222	·213
Sulphur dioxide	2·14	2·06	2·08	2·03	2·08
Methyl iodide	3·48	3·41	3·69	3·62	3·55

§ 7. *Summary of Results.*

The following table collects the final results of the experiments described in this paper. It includes also the results obtained by J. J. THOMSON ('Proc. Camb. Phil. Soc.,' vol. 10, p. 9) and PERRIN ('Rayons Cathodiques et Rayons de Röntgen') for relative conductivities under Röntgen rays, and by MACLENNAN, for cathode rays. It is convenient to quote these here for the sake of comparison.

Gas.	Relative density.	Relative conductivity.							
		Röntgen rays.		Cathode rays.	Radium rays.		Polonium rays.		Uranium rays.
		J. J. THOMSON.	PERRIN.		Penetrating type.	Absorbable type.	I.	II.	
Hydrogen . .	·0693	·33	·026	·069	·157	·218	·226	·219	·213
Air	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
Oxygen . . .	1·11	—	—	1·106	1·21	—	1·16	—	—
Hydrochloric acid . . .	1·27	8·9	8	—	1·46 ?	—	—	—	—
Carbonic acid . . .	1·53	1·4	1·34	1·53	1·57	—	1·54	—	—
Cyanogen . .	1·86	1·05	—	—	1·86	—	1·94	—	—
Sulphur dioxide . .	2·19	6·4	6	—	2·32	1·92	2·04	2·03	2·08
Chloroform .	4·32	—	—	—	4·89	—	4·44	—	—
Methyl iodide	5·05	—	—	—	5·18	3·74	3·51	3·47	3·55
Carbon tetrachloride	5·31	—	—	—	5·83	—	5·34	—	—

§ 8. *Discussion of Results.*

It remains to be considered what conclusions can be drawn from the measurements.

In the first place, let us consider the penetrating radiation from the radium preparation. It will be seen, that in all cases except hydrogen, the conductivity is nearly *proportional to the density of the gas.* Hydrogen is the only case in which the departure from this law is considerable, its conductivity being about double what the law would require. But, since the conductivity of hydrogen is small, the *absolute* difference between the observed conductivity and that which the law would require is not larger than in the other cases. And it is possible that this is the right way of regarding the matter. This aspect of the question is brought out by a graphic representation of conductivity as a function of density. (See diagram No. 6.*) I think that it is impossible to doubt, in view of the results exhibited on this diagram, that the conductivity depends mainly on the density of the gas.

The much greater relative departure from the law in the case of hydrogen naturally raised the question of whether the experiments were open to criticism. They were carefully repeated, taking additional precautions against contamination by impurities. But the accuracy of the former determinations was completely confirmed. There is, I think, no reason whatever to doubt their substantial correctness.†

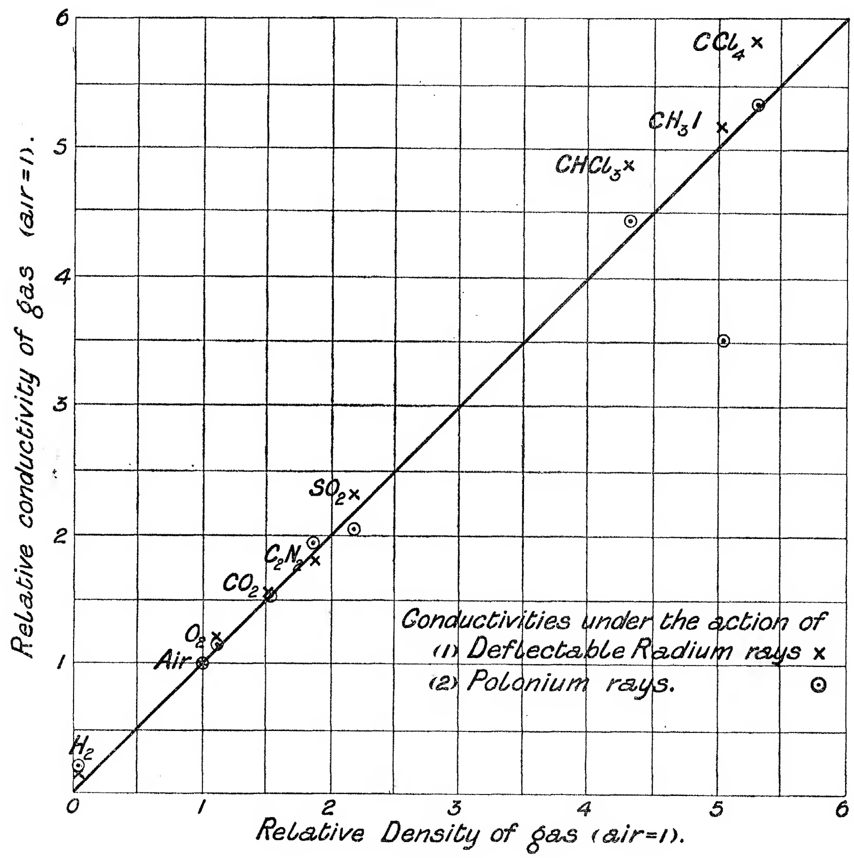
* The determination for hydrochloric acid is not represented in the diagram, because of its uncertainty, mentioned above.

† It is worthy of note, in connection with the large departure of hydrogen from the law of density so

It is certain, therefore, that the relative conductivity of gases under the penetrating type of Becquerel rays are mainly, though not wholly, dependent on their densities.

This result is of considerable interest; the investigations of BECQUEREL, GIESEL, and others have made it clear that rays of this type resemble the cathode rays in many respects. Both are deflected by a magnetic and by an electrostatic field; and carry an electric charge. Here we have one more property in common. For the experiment of MACLENNAN, quoted in the table, established the conclusion that the

Diagram No. 6.



cathode rays too produce a conductivity in gases proportional to the density. There is not, however, the same departure from the law in the case of hydrogen. Under cathode rays the conductivity of hydrogen relative to the other gases is exactly what the law of density would require.

So much for the rays deflected by a magnet. We have still to consider the rays which are not deflectable.

well obeyed by the other gases, that there is large and unexplained discrepancy between the values found for the relative conductivity of hydrogen under Röntgen rays by J. J. THOMSON and PERRIN respectively, although their determinations agree fairly well in most other cases.

In the first place, it will be seen that all the compounds examined gave very nearly the same values for the relative conductivities. There is, in fact, no clear evidence of any difference between them in this respect. This result naturally suggests the conclusion that all these substances give absorbable rays of the same physical nature. Secondly, it will be seen that the non-deflectable rays give somewhat different results from the deflectable ones; these differences being well outside the errors of experiment. For the former, the departure from the law of proportionality is decidedly more marked than for the latter.

A reference to the table will show that these rays give results much closer to the deflectable rays than to the Röntgen rays. The very large conductivities characteristic of compounds of sulphur and the halogens under Röntgen rays are not met with in the case of Becquerel rays of any kind.

It is now very generally agreed that the deflectable Becquerel rays consist of a stream of negative ions proceeding from the radio-active body with enormous velocities (BECQUEREL, 'Comptes Rendus,' vol. 130, p. 109). But this theory gives no account of the nature of the other variety of Becquerel rays. I wish to make some mention of a possible solution of the question, indicating how far it appears to fall into line with the known facts.

Let us, then, imagine that the absorbable rays consist of a stream of positive ions moving from the radio-active body.

Now we know that the positive ions in gases carry the same charge as the negative, and that they have an enormously greater mass (J. J. THOMSON, 'Phil. Mag.,' vol. 48, p. 547). Unless, therefore, their velocity is smaller out of all proportion than the negative ions, it is to be expected that they will be much less easily deflected by the magnet. This theory indicates, then, that by applying a very powerful field, the "soft" rays would be deflected. It would be well worth while to experiment in this direction.

Next, it may be noticed that the smaller penetrating power would be well accounted for by the size of the positive ions, which would, of course, make more collisions with the molecules of the surrounding gas than the much smaller negative ions.

Lastly, the experiments described in this paper seem to indicate that the deflectable rays produce conductivity in gases by the same kind of process as the others—a process quite different from that by which the Röntgen rays produce conductivity. This is in accordance with the suggestion as to the nature of the rays, conductivity being supposed to be produced in each case by the collision of the moving ions with the molecules, and the consequent splitting up of the latter into new ions.

In this investigation I have received much kind encouragement from Professor J. J. THOMSON, and I wish to express my best thanks to him.

Appendix.

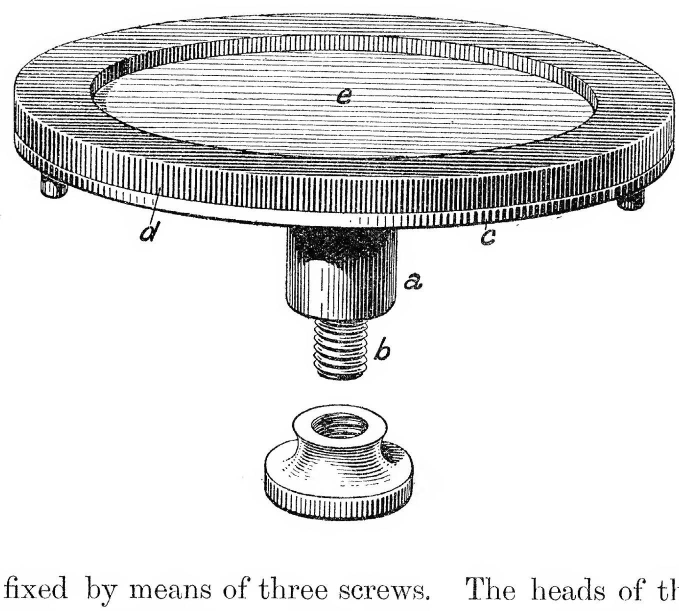
Note on a Practical Point in connection with the Quadrant Electrometer.

Most of those who have had occasion to work with an electrometer of the Elliot pattern must have experienced the difficulty of obtaining a jar of glass that would insulate in a sufficiently satisfactory manner. A jar cannot be considered even tolerably satisfactory unless the charge takes at least a week to leak down to half its original value. Such jars may occasionally be met with, but it is by no means easy to obtain one. It sometimes happens that a jar will satisfactorily retain a small charge for a much longer period than that mentioned, but, if it be charged more highly, the charge rapidly leaks down to a certain small value, after which the loss becomes very much less rapid. But, if the electrometer is required to be highly sensitive, such a jar is of course useless.

The "White Pattern" electrometers are much less subject to this difficulty, because their construction allows of a great length along the glass surface between the charged acid and the outside coating of the jar connected to earth. And it is the surface leakage alone that is practically to be feared.

After trying many jars and failing to obtain a satisfactory one, I adopted an arrangement which has proved very convenient as a substitute. A short brass pillar *a* (fig. 3) carries a circular brass disc *c*. On to *c* a round ebonite plate of the

Fig. 3.



same diameter is fixed by means of three screws. The heads of these screws are on the underside of the brass plate, and they pass into tapped holes in the ebonite, which do not pass right through it. The outside of this ebonite disc is $\frac{1}{4}$ inch thick,

but the inside is turned down until it is very thin—less than $\frac{1}{2}$ millim. Into the circular recess thus formed is dropped a flat brass plate, *e*, of such a size as to fit it loosely. The whole arrangement is fixed horizontally between the pillars carrying the quadrants. For fixing it a screw, *b*, is provided, as a prolongation of the pillar, *a*. This screw passes through a hole drilled centrally in the base of the instrument, and a nut fixes the whole in position.

On *e* is placed a platinum crucible containing strong sulphuric acid, into which the prolonged axis of the needle dips as usual. A charge is given to the top brass plate, which is, of course, in conducting communication with the needle. The instrument can then be used as usual.

The insulation of this condenser has been found very satisfactory, the charge not diminishing by more than 20 per cent. of its original value in a week, and this when the charge was sufficient to make the sensitiveness very high.

One or two remarks may be made in conclusion. If the insulation shows a tendency to deteriorate with time, it can be made as good as ever by removing the surface of the thick rim of ebonite in the lathe, with emery paper, subsequently polishing the surface with bath-brick, applied on felt.

A platinum cup was employed for the acid, with the idea that with it there would be no tendency to any creeping of electrification, and consequent uncertainty in the potential of the needle. But very probably glass would be practically as good. A platinum wire dipping in the acid would then have to be connected to the upper brass plate.

Although there is no novelty in principle in this contrivance, yet it has proved so convenient in practice that it has been thought worth while to describe it.